Simple Machines
A Kid's Guide
VIKRAM A SARABHAI
COMMUNITY SCIENCE CENTRE

## Vikram A Sarabhai Community Science Centre
## Ahmedabad, India

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# Simple Machines

*A Kid's Guide*

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Simple Machines - A Kid's Guide

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# Preface

We are happy to bring to you this booklet 'Simple Machines - A Kid's Guide' which is an attempt to make learning of complex things simple.

Machines have transformed the way we live. They have become such an integral part of our lives that we use a machine without even realising that we have used one! Many a times we do not know how the machines and gadgets that we use, work. They seem too complex! But, just as complex things are made up of simple building blocks, all complex machines that we use are actually made up of simple machines like lever, inclined plane, wedge, pulley, wheel and axle and screw.

This booklet will help generate curiosity to know 'How things work?'. It would serve as a beginner's guide for the children who want to enter the world of simple machines. This booklet may be used as a supplement to the school curriculum as it covers the concepts dealt at the primary and upper primary levels. Written in a simple manner, it will also be useful for parents and teachers to facilitate learning of the basics of simple machines.

Dilip Surkar
Executive Director

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# Introduction

Look around and you will see a variety of machines being used everywhere. Bicycles, buses, cars, trains, trucks, cranes, aeroplanes, escalators, etc. are examples of machines. You are surrounded by machines even in your home, right from complex ones like clocks to simple ones like door handles, knives, tongs, scissors, ladle, etc. Some of these are mechanical like a pendulum clock, while some are electronic like a television or a computer.

However big and complicated these mechanical devices may look, they are made up of smaller interlinked units. In physics, the word 'simple machines' is used for these smaller units. A hinged door may not seem like a machine to you but it is, in fact, one such simple machine. Just imagine how difficult it would be to move a large door without a hinge every time you wanted to move in and out of a room! A crane used for lifting heavy loads is made up of many pulleys, each of which is a simple machine.

This booklet describes such 'simple' yet important machines. It is aimed at children and will help them understand how these little wonders make our work easier. Illustrations and explanations have been provided to give a clear idea. Go right ahead and enjoy!

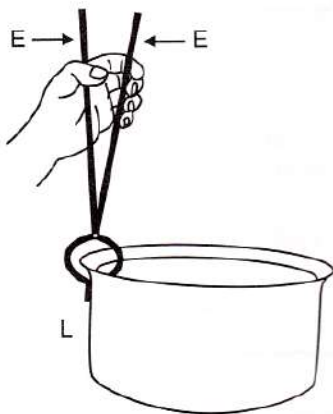
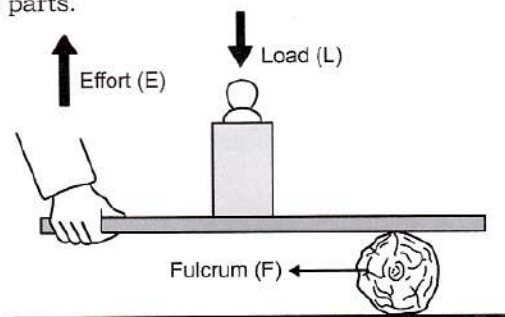
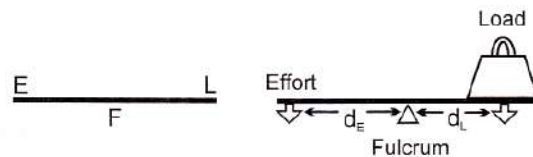
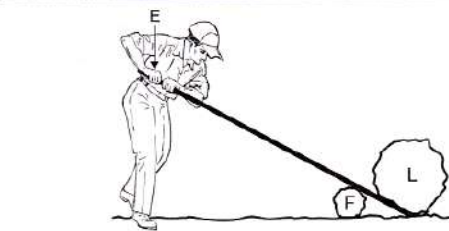
## Idea behind Simple Machines

Have you tried lifting heavy loads? Have you pushed heavy loads? If it is too hard for you, you might consider taking another person's help or using an animal to reduce the effort. However, there are some clever ways to make work either easier or faster. In physics, these clever devices are called simple machines.

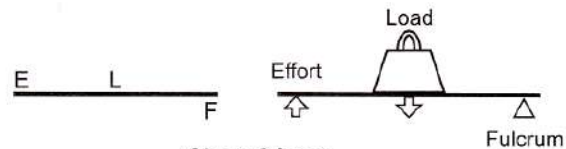
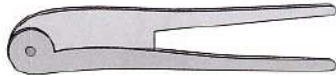
We constantly depend on simple machines. Think of the following:

- How easy is it to cook without a ladle or a pair of tongs?
- Aren't scissors a neat way of cutting things?
- What made people start using a pulley to draw water from a well?
- Imagine dragging a heavy box instead of carrying it on a hand-cart!
- Can you sharpen a pencil without a sharpener or a blade?
- Why does a car mechanic use a car jack to raise a car?

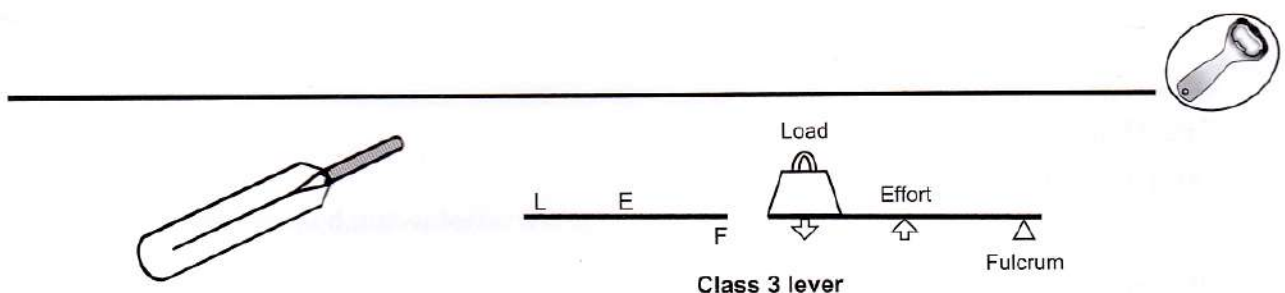
# Lever

Hold a cooking pot using a pair of tongs. If you press the ends together with more force, the pot is less likely to slip. This means that the force you apply is transferred by the pair of tongs onto the pot. The diagram below will make it clear.

The pair of tongs acts like a simple machine called a lever. A lever transfers force applied at one of its points to another point, where the load is located. One point on the lever arm always remains fixed, the rest of the lever rotates about this point. This fixed point is called the 'fulcrum'. The part of the lever between the effort and the fulcrum is called the 'effort arm'. Similarly, the part between the load and the fulcrum is called the 'load arm'. All levers have these three parts.

After reading the previous example, you might have realized that there are different kinds of levers. Levers can be classified according to the position of the load, effort and the fulcrum.

**Class 1 lever**

**Class 1 lever:** The fulcrum is located somewhere between the effort and load. The fulcrum changes the direction of force. Downward effort moves the load upwards and upward effort moves the load downwards.

Common examples: Scissors, crowbar, claw hammer (nail-removing hammer), weighing scales

**Class 2 lever**

**Class 2 lever:** The load lies between the effort and the fulcrum. The fulcrum is usually closer to the load. The direction of the force does not change but the force gets multiplied so even a small force becomes sufficient. Pressing upwards on the lever arm pushes the load upwards.

Common examples: Bottle opener, mango cutter, lemon squeezer

**Class 3 lever**

**Class 3 lever:** In this class of levers, the effort is between the load and the fulcrum and there is usually a loss in force. There is no change in the direction of force. Both the load and the effort move in the same direction. Common examples: Cricket bat, Fishing rod

In each of the above examples, the lever action gives us some advantage. We can understand the advantage by some formulae. For all levers we can write

$$E \times d_E = L \times d_L$$

Here $d_E$ and $d_L$ are the lengths of the load and effort arms respectively.
The ratio L/E is called the mechanical advantage (MA) and the ratio $d_L/d_E$ is called the velocity ratio (VR).

In class 1 levers, MA > 1, but VR <1.
In class 2 levers, MA > 1, but VR < 1
In class 3 levers, MA < 1, but VR > 1
For all classes, MA x VR = 1

Thus, in a class 1 or a class 2 lever, you gain by applying a small force, as in a bottle opener. In a class 3 lever, you gain by getting a larger speed of the load, as in a ball hit by a bat.

## Try this...

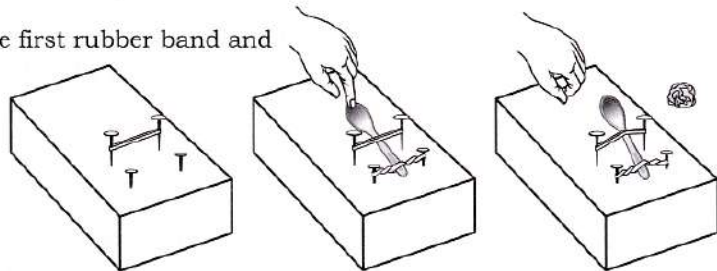
### Catapult Shooter

In ancient times, catapults were used as weapons. They were used to hurl huge stones over the high walls of forts into the city or palace during a war.

**What will you need?**

A block of wood, two large and two small nails, two rubber bands, a hammer, a plastic spoon, paper

**What should you do?**

- Ask your parent or teacher to hammer four nails into the block of wood as shown in the figure such that the two large nails are about three centimetres behind the small nails.
- Connect the two large nails with a rubber band. Use another twisted rubber band to connect the other two small nails.
- Insert the handle of the spoon under the first rubber band and then through the twisted second rubber band.
- Hold back the bowl of the spoon as shown in the figure.
- Place a small piece of crumpled paper in the bowl of the spoon. Let go of the spoon to see your catapult work!

## Mightier Levers

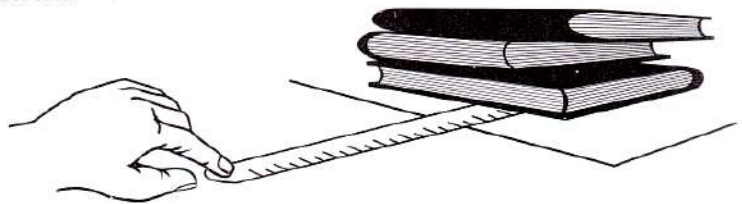
**What will you need?**

Two rulers of different lengths, a notebook, a desktop or a table

**What should you do?**

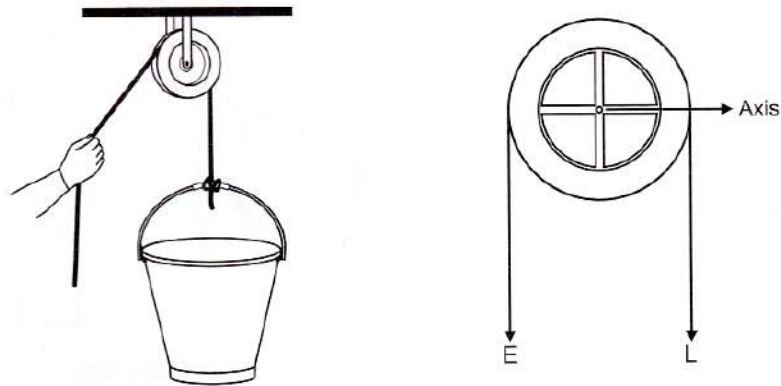
- Lay the longer ruler on a table or a desk with part of it hanging over the edge. Place a notebook on the other end. Try to lift the book by pressing down on the part of the ruler that overhangs the table.
- Move the book closer to the edge by pulling on the ruler and try lifting the book. Did you need less or more effort than the previous attempt? Repeat this activity until the book is right on the table's edge.
- Now repeat the same activity using the shorter ruler and consider the effort needed every time. Was it easier to lift the book with the shorter ruler or the longer one?

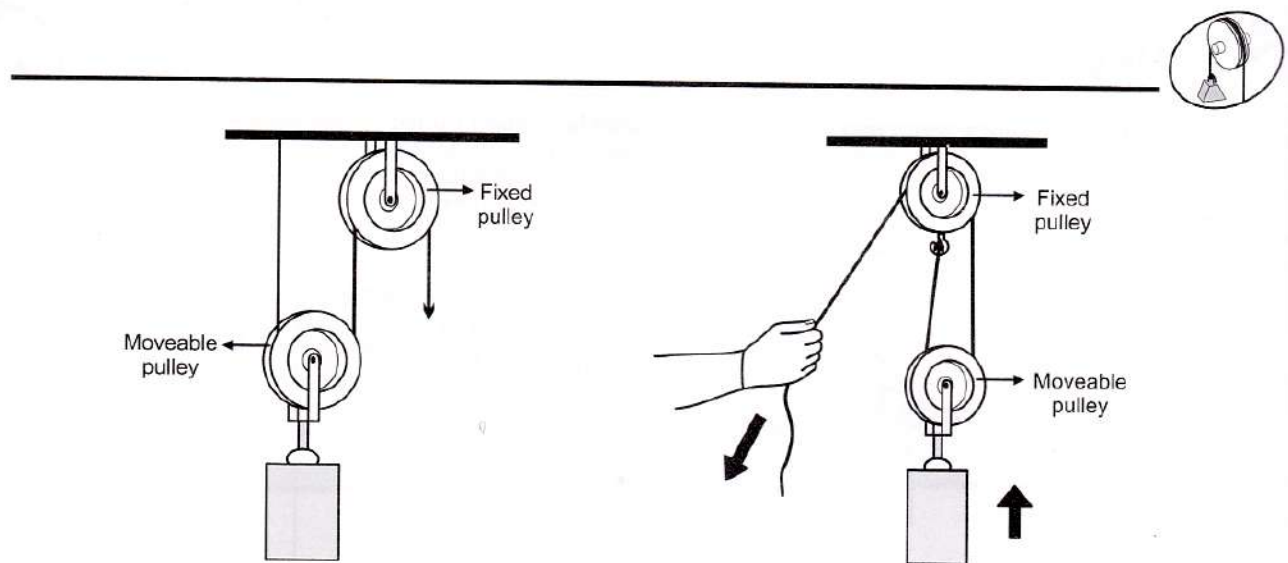
**What did you learn?**

- What acted as the lever? What was its fulcrum? What were the load and the effort?
- Which class of lever did this experiment demonstrate?
- How do the load arm, effort arm and the effort change, as the book is moved closer to the edge of the table?

## History

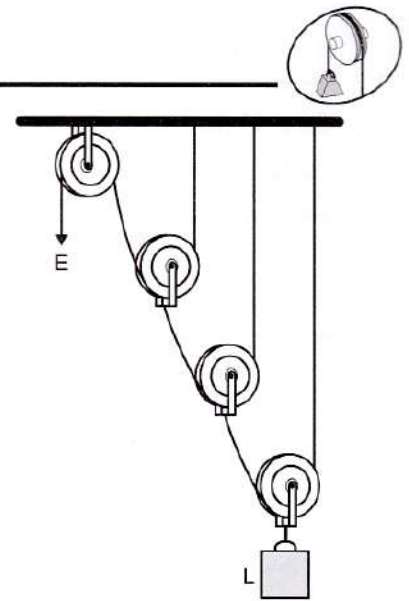
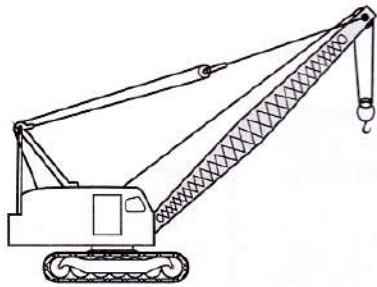
The lever is one of the earliest and simplest of machines. From prehistoric times, levers were used in cultivation, excavation and moving large objects. Levers were first described around 260 B.C. by the ancient Greek mathematician, Archimedes. Around 5000 B.C., a lever was used in a simple balance scale used to weigh gold and other items. Around 1500 B.C., a machine called the *shaduf*, the predecessor of the crane, was used in Egypt and India for lifting containers of water. The ancient Egyptians used levers to pick up large blocks of stone during the construction of pyramids. The ancient Romans used catapults to hurl stones at their enemies.

# Pulley

Have you tried pulling water out of a well? You would have then pulled a rope running over a grooved wheel. At the end of the rope is the filled bucket. Thus, you pull downward to lift your bucket up. The device used is a pulley. It is a wheel with a groove, rotating around a fixed line called the axis. A pulley changes the direction of applied force, but does not reduce your effort.

A pulley and a lever are closely related. A pulley can be compared to a class 1 lever, with equal load and effort arms. The axis plays the role of the fulcrum.

As you saw, the pulley described above does not reduce your effort, but lets you apply a force in a more comfortable manner. By using more than one pulley, you can even reduce the effort! Let us see how.

In the above arrangement, you can reduce the effort to half of that with a fixed pulley. However, the load moves only half the length of the rope you pull. Thus, the mechanical advantage is 2, and the velocity ratio is ½. This two-pulley combination is like a class 2 lever, where the load lies between the fulcrum and the effort.

If you further increase the number of pulleys, you will successively reduce the effort. Notice that some pulleys in the diagram rotate but do not move, while others rotate and move at the same time. You can imagine various combinations of fixed and movable pulleys to enable you to lift very heavy loads with a small effort.

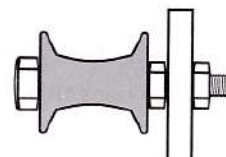
A crane uses this trick!

Have you ever spotted a pulley in your home or anywhere around you?

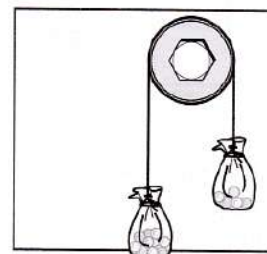
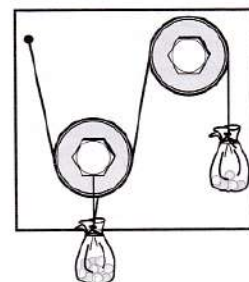
During Independence Day and Republic Day celebrations, the flag is hoisted up the flagpole using a pulley. You raise and lower your window curtains or blinds using a pulley. In villages, a pulley is used to draw water from a well.

## Try this...

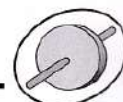
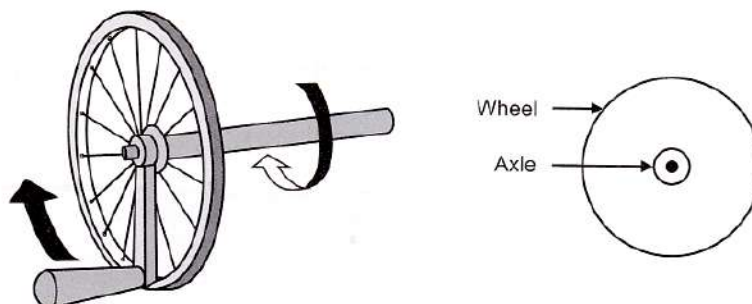
### Let's make our own pulley!

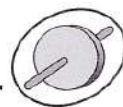
#### What will you need?

A stiff cardboard, two spools with a hole through their axes, two long bolts with two nuts each (the diameter of the bolt should be slightly less than the diameter of the spool), a piece of string, two small handkerchiefs, 20 marbles

#### What should you do?

- Drive the bolt through the hole in the spool and then fit a nut. This will hold the spool in place.
- Now, make a hole in the stiff cardboard whose diameter is slightly lesser than that of the bolt. Drive the bolt with the spool through this hole in the cardboard. Through the opposite end, again fix a nut to hold this entire arrangement in place.
- Now, tie a handkerchief to each end of the string by gathering all the corners of each handkerchief in such a way as to form a small pouch. Pass the string over the groove of the spool.
- Your pulley is ready! This is a single pulley.
- Place 10 marbles in one of the pouches. In the other, put marbles one by one and see how many marbles are needed to balance both the sides.

- Next, modify the arrangement slightly. As shown in the figure, we will add another pulley. But this pulley is not fixed to the board. Tie a pouch to the axis of this pulley. Pass the string over the grooves as shown.
- Put 10 marbles in each pouch. Remove marbles from one of the pouches, one by one, until you have minimum number of marbles that can still balance the 10 marbles on the other end.
- You must have seen that, increasing the number of pulleys reduces the effort required on the other end to lift the load.
- Can you try the same activity with three pulleys or even more?

## History

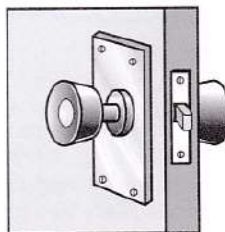
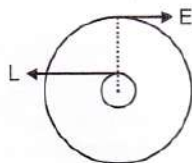
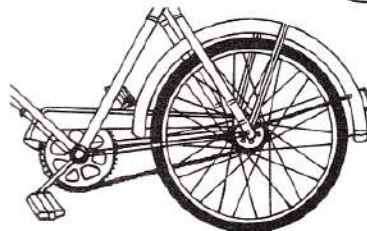
Pulleys have been used for centuries to lift heavy loads. The earliest pulleys probably made use of a rope over a tree branch to lift heavy objects. The first pulley systems were probably made up of tree trunks or branches with the rope over the horizontal part of the system. Later, wheels were also incorporated in these pulley systems. Pulleys were then used to raise and lower the sails of ships with ease. Around 1100 A.D., pulley systems employing many pulleys were used in the construction of huge buildings.

# Wheel and Axle

Just before Uttarayan, many of you must have got your *manja* (the string used for flying kites) coloured and coated with glass powder. The *manjawalla* (person who prepares the *manja)* winds the *manja* over a spindle while rapidly turning a handle. The larger the handle, the faster the string gets wound. The machine used is yet another example of a simple machine. It is called a wheel and axle.

A close look at a moving wheel will immediately tell you that a wheel actually has a rotating outer disc and a smaller central disc. The central disc is called the axle. Effort is applied to the wheel, which rotates about the axle. The mechanical advantage of wheel and axle is

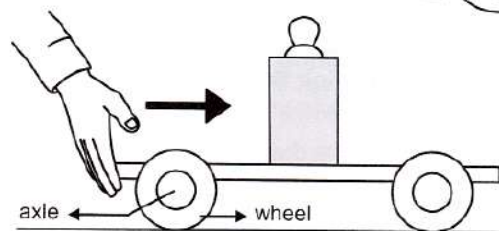
MA = diameter of the wheel/diameter of the axle

Very often you have combinations of two or more wheels and axles working together. A bicycle pedal, chain and wheel is one such example. Turning the pedal once usually turns the wheel 2-3 times. Thus, you gain in velocity. The gain is expressed by the velocity ratio

VR = diameter of the axle / diameter of the wheel

Hence, a wheel and axle can produce a gain in either effort or velocity, depending on how it is used.

A wheel and axle is really a lever of class 2, which goes round and round. Like all levers, this one too has a fulcrum. It is the centre of the wheel, which remains still.

Can you now recognise the similarity between a wheel and axle and a pulley?

A widespread use of a wheel and axle is made in all kinds of machinery. A wheel with teeth on its circumference is called a gear. You can go to a car or workshop or visit a small factory to find out how gears are used.

A rolling wheel is also used to transport an object. It cuts down on the friction between the object and the surface over which you are rolling it. Only a small part of the wheel touches the ground. So there is less friction. The larger the diameter of the wheel, the easier it is to make something roll. Usually two wheels on a common axle are used, to make it easier to balance a load.

## History

Wheel and axle is one of the most important inventions in history. Logs were used to move huge rocks by rolling them along. These logs gave rise to the wheel and axle around 3000 B.C. It is believed that the wheel and axle combination originated in ancient Mesopotamia during the fifth millennium B.C. The principle of wheel and axle was used in the potter's wheel, vehicles and in the wheels used in mills. The wheel reached Europe in the fourth millennium and India with the Indus Valley Civilization in the third millennium.

## Try this...

### Make a small cart

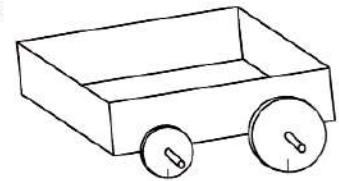
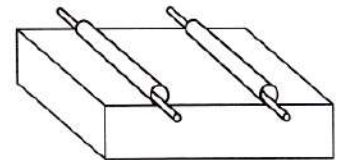
**What will you need?**

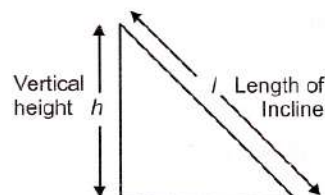
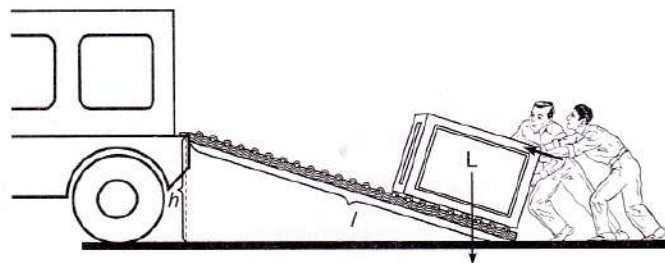
Thick cardboard, two discarded short ball pen refills, a matchbox, scissors, a straw, sticky tape, a pencil or sketch pen, a compass

**What should you do?**

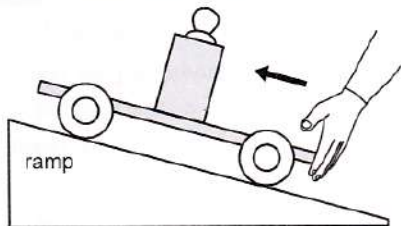
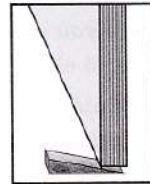
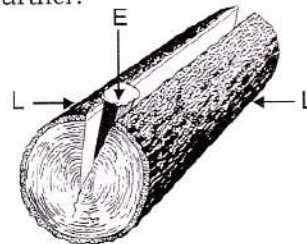
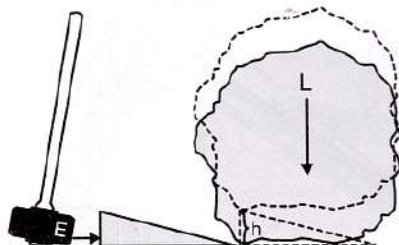
- Cut the straw into two pieces, the length of which has to be kept equal to the width of the matchbox. Fix these pieces of straw using a sticky tape onto the bottom of the matchbox, near the two edges (along the width of the matchbox) as shown in the figure. Pass a refill through each straw.
- Now cut two similar large and two similar small circles from the thick cardboard. Make a mark on the edge of each circle using a pencil or a sketch pen. Using the point of the compass, make a tiny hole in the centre of each circle. Push a circle on each end of the refill through the hole as shown in the figure.
- Your cart is now ready! The two smaller circles act as front wheels and the larger circles are the rear wheels.
- Keep the marks on all the wheels pointing towards the ground. Now move the cart so that the mark on the small wheel completes one full circle, observe how far the mark on the large wheel has turned.

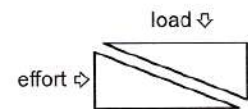
**What did you learn?**

- Which part of the cart acts as the wheel? Which part acts as the axle?
- The wheels (here, cardboard circles) on a vehicle turn around a long rod (here, pencil) called an axle.

# Inclined plane

Have you watched vehicles climb up a hill? They go round and round over gradually rising road slopes, instead of straight up. This way even vehicles with little power can climb a hill. When an object is moved over a gradual incline, less effort is needed than lifting it straight up. But you must move the object over a greater distance. When raising a heavy box, it is much easier to pull it up a ramp than it is to lift it straight up. The simple machine in each of these examples is an inclined plane.

An inclined plane helps you overcome a large resistance by applying a relatively small effort force. But as explained earlier, the load has to be moved a longer distance over the inclined plane than the actual length to which the load has to be raised. The mechanical advantage is large if the angle of the incline is small.

$$MA = \text{length of incline}/\text{vertical height}$$

The distance that needs to be covered to gain a particular height increases as the angle of the incline becomes smaller.

You can combine a wheeled cart and an inclined plane to reduce your effort even further!

A wedge is used by carpenters to split things apart. A woodcutter uses an axe to chop a strong log with small effort. A doorstop stops a door from banging even in a fierce wind.

A wedge can also be driven under a heavy object to lift it little by little, as shown in the picture. A small effort can be sufficient to create a large force by using a wedge.

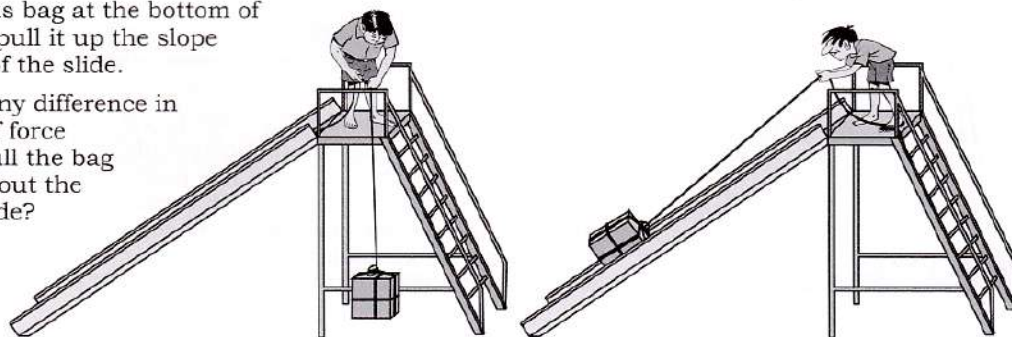
A wedge, as you must have guessed, is a kind of inclined plane! In an inclined plane you push things over it, but if you push the inclined plane under an object, it becomes a wedge. A thin wedge enables you to resist a large load with a smaller effort than that required for a thick one.

## Try this...

### A Slide the Giant Plane

**What will you need?**

Playground slide, a heavy bag/box full of books or stones, 1 long rope

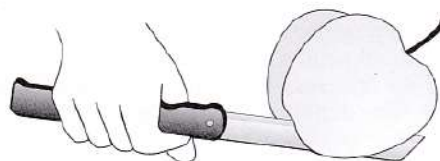
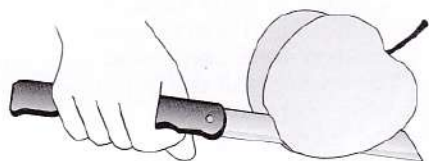
**What should you do?**

- Take a heavy bag of books (or stones) and tie it with a long rope of length slightly longer than the length of the playground slide.
- Hold the free end of the rope and climb up the top of the slide. Now, pull the rope and try to lift the bag straight up. Consider the amount of force required.
- Now, place this bag at the bottom of the slide and pull it up the slope from the top of the slide.
- Did you feel any difference in the amount of force required to pull the bag with and without the help of the slide?

## Sharp vs. Blunt!

**What do you need?**

A sharp knife, a blunt knife, an apple (or a potato)

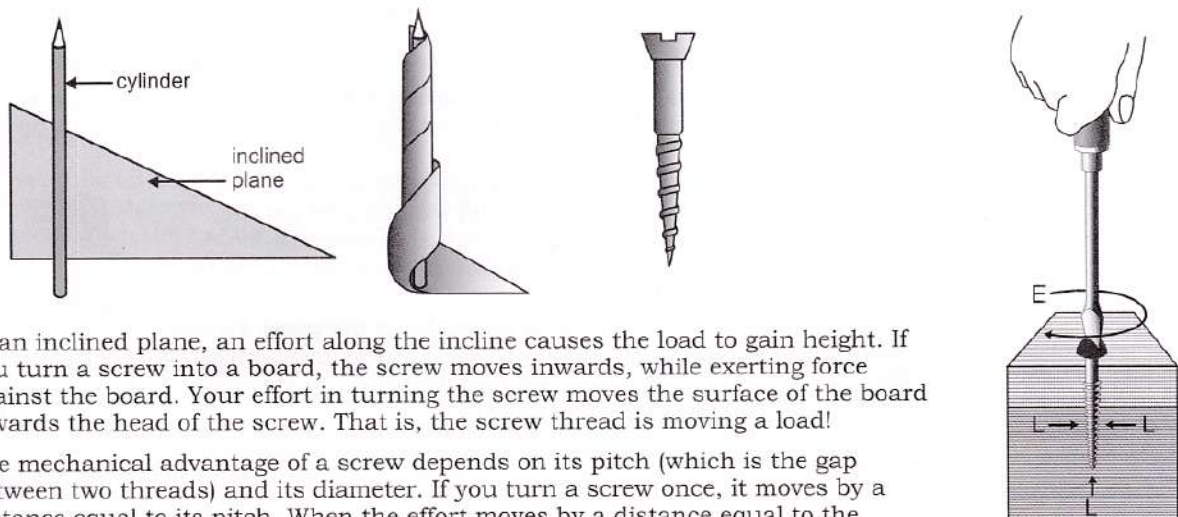
**What should you do?**

- Take an apple and use a sharp knife to cut it.
- Now again try to cut an apple using a blunt knife. Instead of a blunt knife, you can use the thicker edge of the same sharp knife for cutting.
- Which of the knives (or edges) cuts an apple with less effort?
- Can you explain this in terms of the angle of the wedge?

## History

The pyramids in Egypt are made of huge stone blocks weighing 2 to 70 tons. It is thought that Egyptians used inclined planes to move these blocks to the top of the pyramids during construction. As the pyramid grew taller, the ramp had to be extended in length, and its base was widened, to prevent it from collapsing. Inclined planes more than a mile long were required to place these blocks on the top! It was also used in the construction of other huge stone structures, roads and water canals called 'aqueducts'. Scientists like Galileo Galilei performed experiments with inclined planes to study the laws of physics.

The origin of the wedge is unknown because it has been in use as early as the Stone Age. The sharp rocks that were used by the prehistoric men to hunt and also to scrape the skins of the dead animals were also wedges! In Australia, the wedges were used for at least 4000 years, to remove bark from trees in large single slabs. The economy of the Indus valley civilization depended on trade, which was carried out using boats. The early boats used during the period of Indus valley civilization were made by using wedges.

## Screw

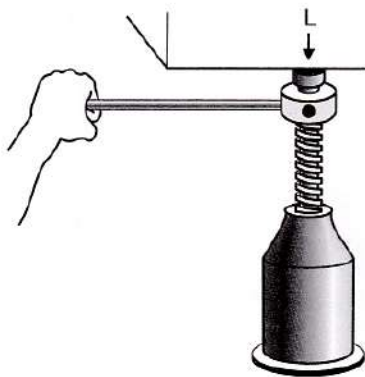
Cut a paper in the form of a right-angled triangle. Roll this paper on a pencil, as shown here. Now, take a screw and compare it with the pencil which has the paper wound on it. Do you notice a similarity? The threads on a screw are like a rolled up inclined plane. The similarity between a screw and an inclined plane is not only in appearance, but also in their principle of working. Let us see how.

In an inclined plane, an effort along the incline causes the load to gain height. If you turn a screw into a board, the screw moves inwards, while exerting force against the board. Your effort in turning the screw moves the surface of the board towards the head of the screw. That is, the screw thread is moving a load!

The mechanical advantage of a screw depends on its pitch (which is the gap between two threads) and its diameter. If you turn a screw once, it moves by a distance equal to its pitch. When the effort moves by a distance equal to the

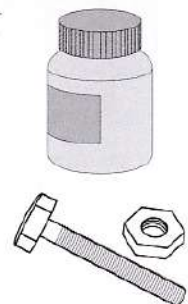
circumference, the load moves by a distance equal to the pitch. Thus,

$$MA = \text{circumference}/\text{pitch}$$

$$VR = \text{pitch}/\text{circumference}$$

You would have realized that a fine pitch screw (one with closely spaced threads) needs to be turned more number of times to advance a given distance, as compared to a coarse pitched screw (one with widely spaced threads). On the other hand, a fine pitch screw needs less effort to tighten it.

A fine example of a screw moving a load is a car jack. By applying very little effort to turn the handle of the car jack, you can lift up a car single-handedly!

Yet another common use is the lid of a jar. Here, you have a screw on the lid moving over another screw on the bottle. Such a combination is commonly used in all kinds of machinery – it is the familiar nut and bolt.

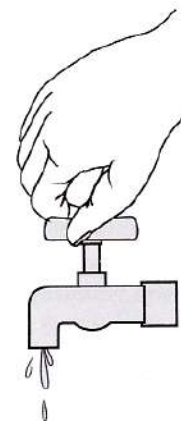
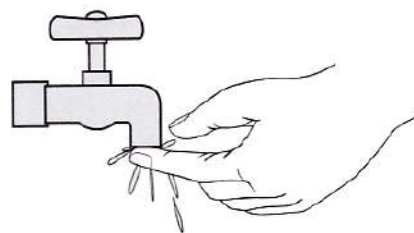
There are many many examples of the uses of a screw. It is impossible to think of any machine in day-to-day occurrence that does not use a screw!

## Try this...

### Let's see how a small screw saves a big effort...

**What will you need?**

A tap with flowing water

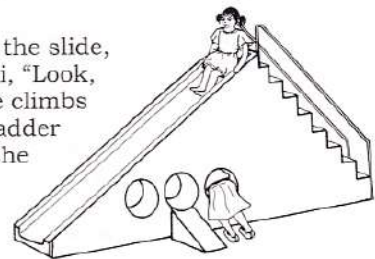
**What should you do?**

- Turn on the tap completely to get a heavy flow of water.
- Try to stop this flow with your finger. Consider the effort required.
- Now, turn off the tap gradually by slowly turning its handle (or knob). Again, consider the effort required. Count the number of times that you have to turn the handle (or the knob) to stop the flow of water completely.
- You must have observed that applying little effort to turn the handle (or the knob) of the tap stops the heavy flow of water, which otherwise would have required a lot of effort. However, you have to turn the handle several times!
- Can you say whether the effort required to turn off the tap would be greater or lesser if you had to turn the handle only once?
- How would that compare to turning the handle many number of times?

## History

Around 200 B.C., a Greek mathematician named Apollonius of Perga studied the laws governing the working of screw. In the third century B.C., Archimedes invented a screw machine to lift fresh water from the hold of a ship, which is called Archimedes' screw and is still used today for transporting water. Screws were in use around 79 A.D. This was proved when a machine called an olive press, was excavated from Pompeii in Italy. Early screws were made from wood and were used in wine presses, olive oil presses and for pressing clothes. In the thirteenth century, screw hoists were used to raise loads. Towards the end of the 1400s, jackscrews were used to lift wagon wheels for repairs. Metal screws and nuts used to fasten two objects together first appeared in the fifteenth century.

# A Day with Simple Machines

**Read the story. Some parts are italicised; these parts refer to some activity, which involves a simple machine. Can you find out the type of simple machine being used in that activity?**

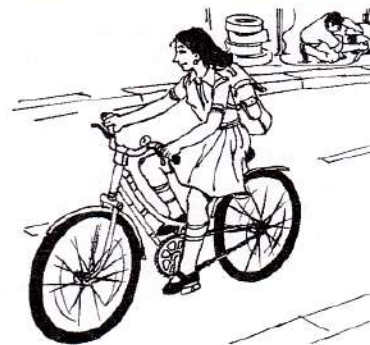
Riya loves playing in the park with her friends. Today she is playing on the slide, she climbs up the slide and slides down, what fun it is! She says to Niki, "Look, *how I climb the slide*!" She does not use the ladder to climb, instead she climbs it from the front. "This way I don't have to run all the way back to the ladder everytime I reach down", she adds and starts climbing the slide. Does she easily get to the top? The slide rises gradually and then becomes steeper. She initially enjoys it, but later on she has to put in a lot of effort to climb it. She is perspiring. Niki laughs at her as Riya tries hard to climb the slide...

She hears a voice, "Riya, wake up!" Riya opens her eyes and realises that it was only a dream. But, she is all covered with sweat. "It's very hot today!", she thinks as *she turns on the fan*.

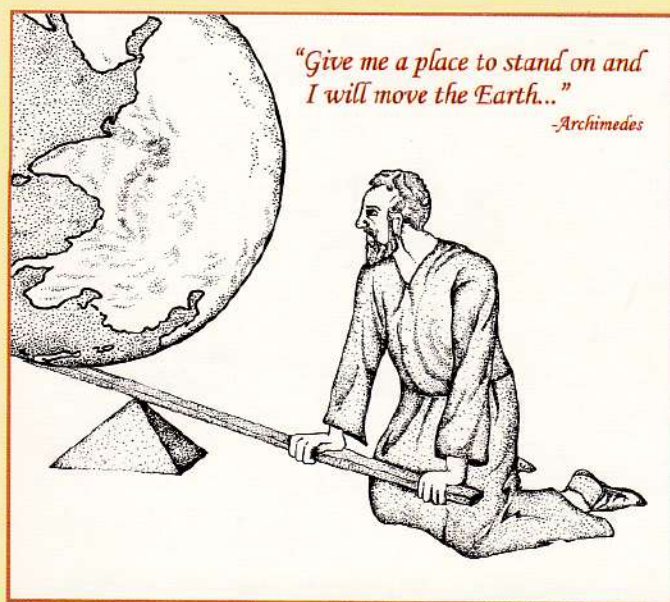
She gets ready for school. "Mummy, I want to have a lemonade today, it's so hot!" says Riya. Mummy *opens the jar of sugar* and puts some sugar in water. She, then, *takes a knife and cuts a lemon* into two. Then *she puts a half lemon in the lemon squeezer and squeezes it*

into the sugar syrup. The lemonade is ready. She calls Papa for breakfast. "*I am shaving,* you go ahead", replies Papa.

Riya *rides her bicycle* to school. As she pedals fast, Akshat waves to her from *his school bus*. She is going to be late for school today! *She sees a huge crane picking up an old car.* "Wow! This crane can really pick up heavy things!' she exclaims. "How I wish it would lift me up and take me to school!". As she reaches farther, she sees that Akshat's bus has a flat tyre. *One side of the bus was raised up and the driver was changing tyres.* Akshat waves to her again.

At school she learns about simple machines. She learns about the lever, pulley, wheel and axle, inclined plane, wedge and screw. She likes it. Her class teacher informs the class, "Tomorrow is the Independence Day. We are *going to have the flag hoisting ceremony at our school.*"

Riya comes back home from school. *She takes a bottle opener and opens a bottle of cold drink.* "It's so hot today!", she thinks for the hundredth time that day as she switches on the T.V. *A woman is pulling water from a well.* Riya sees the water and wishes it would rain. She changes channels. There is a hockey match going on. *She likes the hockeystick*; it reminds her of a candy stick! Suddenly, the door slams shut. *She opens the door and while she is putting a doorstop*, there is lightning and sound of thunder. A good wind is blowing. Before she can think it starts raining. She is happy because it is not hot anymore!

## More to ponder over . . .

We hope you liked this book. Did it help you appreciate how simple yet clever ideas form the basis of machines around you? When you next see a machine, try to break it down (mentally!) into parts. Think hard... you will soon figure out which of the basic simple machines are working hand in hand inside the machine. May we suggest a few things to try out? Go to a construction site and look around. Or go and spend some time in a bicycle repair shop and figure out how the pedals, wheels, handle bars are basically made up of simple machines. Even better, try to build something on your own!

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